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**A LABORATORY FURNACE FOR TESTING
RESISTANCE OF FIREBRICK TO
SLAG EROSION**

BY

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CONTENTS

	PAGE
I. INTRODUCTION	5
1. Service Conditions for Boiler Furnace Refractories	5
2. Acknowledgments	6
II. LABORATORY SLAGGING TEST FURNACE	6
3. General Description of Furnace	6
4. Furnace Details	6
5. Feeding of Slag	9
6. Driving Mechanism	10
III. METHOD OF CONDUCTING TESTS WITH FURNACE	10
7. Method of Setting up Furnace for Test	10
8. Method of Furnace Operation	10
9. Removing and Measuring Test Bricks	13
IV. RESULTS OF TESTS	13
10. Results with Synthetic Slag	13
11. Results with Coal-Ash Slag	14
V. SUMMARY	17
12. Advantages of This Type of Furnace	17



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A LABORATORY FURNACE FOR TESTING RESISTANCE OF FIREBRICK TO SLAG EROSION

I. INTRODUCTION

1. *Service Conditions for Boiler Furnace Refractories.*—The operation of boiler furnaces with mechanical stokers at high ratings has greatly reduced the life of refractories in arches, side walls, and bridge walls. The action of slag from coal ash of low fusibility and high iron content, as in the case of many Illinois coals, is especially severe and causes a rapid erosion of the refractory. Service conditions and the factors affecting the life of refractories in several types of boiler furnaces have been discussed by Sherman and Taylor*

Temperatures as high as 2700-2800 deg. F. are found at the inner faces of refractories fired with chain-grate stokers. While this is well below the softening point of the refractories used, the coal-ash slags are, in many cases, quite fluid and extremely active in their attack. Atmospheric conditions are frequently somewhat reducing, thus increasing the activity of slags high in iron content.

Fine particles of coal ash are carried by the furnace gases at velocities as high as 40 feet per second and deposited on the face of the brick linings where the slag fuses and flows down over the surfaces. The coating of slag effectively protects the refractory from abrasive effect due to impingement of the slag particles, but the velocity of the gases distinctly affects the flow of the slag. The flow of the slag is, without question, one of the most important factors in the erosion of the refractories. It results in a continual removal of dissolved material along with grog particles and renewal of the coating of fresh slag on the brick surface. If such flow did not take place the slag in contact with the refractory would soon become sufficiently viscous, due to dissolved clay material, to act as a protective coating of the brick.

In an investigation of the slagging effect of Illinois coal ash on refractories a laboratory testing method was sought which would determine the relative resistance of different bricks to such slags in terms which might be correlated with the results obtained in service in boiler furnaces. The simulated service test was found most applicable for this purpose. Difficulty was found in obtaining equal heat treatment and uniform slag application on test bricks under con-

*Sherman, R. A. and Taylor, E. "Service Factors Governing the Slagging of Boiler Furnace Refractories," Mech. Eng., July, 1917.

ditions representative of boiler furnace operation. As a result of considerable effort and trial of several methods, a furnace and a testing method were developed which give a very satisfactory simulated service test.

2. *Acknowledgments.*—The work herein presented is a part of an investigation undertaken by the University of Illinois Engineering Experiment Station, of which DEAN M. S. KETCHUM is the director, in the Department of Ceramic Engineering, of which PROF. C. W. PARMELEE is the head.

The investigation was carried on in coöperation with the UTILITIES RESEARCH COMMITTEE representing several public utility organizations in Chicago and vicinity.

Work is being continued in the testing of various refractories in coöperation with the Special Research Committee on Boiler Furnace Refractories of the American Society of Mechanical Engineers, of which Mr. C. F. HIRSHFELD is chairman.

II. LABORATORY SLAGGING TEST FURNACE

3. *General Description of Furnace.*—A general view of the furnace and its auxiliary equipment is shown in Fig. 1. A cylindrical furnace chamber is supported vertically on rollers and is rotated about its axis during the test. It is heated to any desired temperature with controlled atmospheric conditions by a blast burner using city gas and air, both at high pressure. Powdered slag is fed at a uniform rate through the burner and impinges with the blast on the vertical faces of the standard-sized test bricks which form the lining of the chamber. The melted slag flows down over the faces of the bricks and out through a port in the middle of the furnace bottom.

By rotating the furnace, each test brick is brought successively and repeatedly into position before the burner. Identical temperature conditions and uniform slag treatment for the several bricks is thus insured. A close control of both temperature and furnace atmosphere can be maintained to simulate conditions in the boiler furnace.

4. *Furnace Details.*—Details of the furnace and equipment are shown in Fig. 2. Sixteen test bricks *T* are set on end with the $2\frac{1}{2}$ in. by 9 in. faces lining the chamber. These alternate with special arch bricks *U* to form a circle of $14\frac{1}{2}$ -in. inside diameter. The lining is carefully laid up with thin mortar joints of fireclay and fine grog. The lining is backed by $2\frac{1}{2}$ in. of Sil-o-cel brick placed on end inside the steel jacket *E*. The jacket is split vertically into half sections to

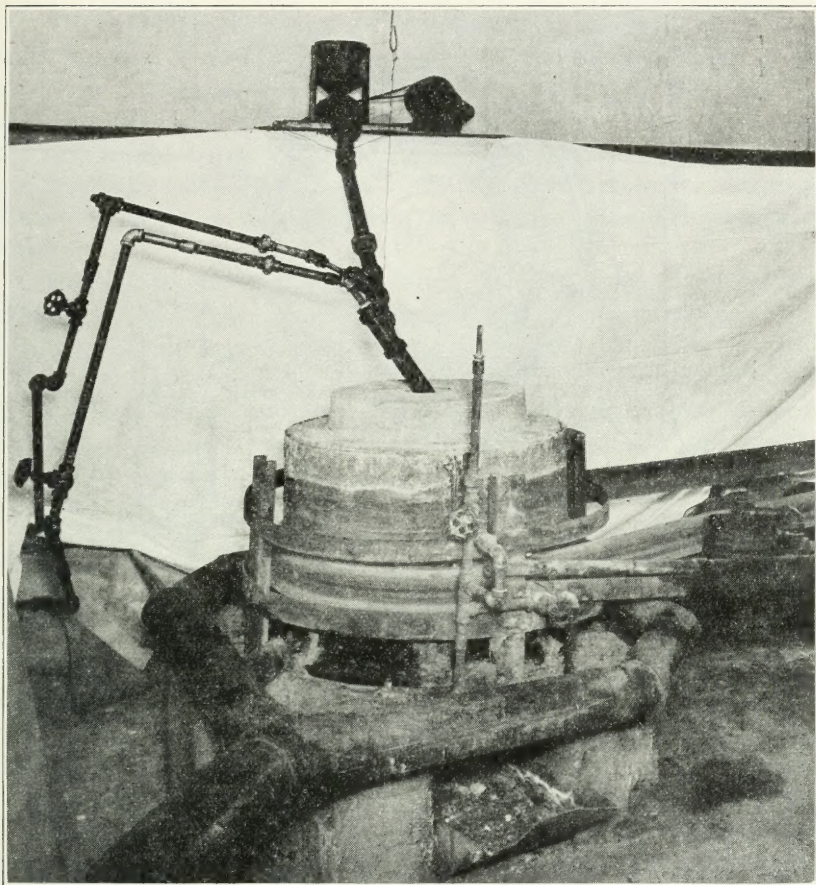


FIG. 1. VIEW OF SLAGGING TEST FURNACE AND DRIVING MECHANISM

facilitate removal after a test. Angles at the ends of each section are drilled for take-up bolts to fasten the segments together.

The bottom of the chamber is formed by a circular center block *Q* and eight circle blocks *R*. A hole 5 in. in diameter in the middle of the circle block provides for exit of the melted slag.

The bottom blocks are supported by a cast-iron tire rim *C* and eight radial arms *A*. The arms are bent up vertically at the outer end to support the steel belt band *B* which is fastened to them by rivets with countersunk heads on the belt side. A flange *F* is fastened to the under side of the arms to support the driving belt. The tire *C* is L-shaped in section and is machined on the bottom and outside where it bears on the supporting rollers and guide rollers, respectively.

The furnace is supported on eight horizontal rollers *H* and is centered and held in place against the tension of the driving belt by guide rollers *G*. Both sets of rollers are made of heat-treated steel and run on tempered chrome-vanadium steel shafts supported by cast-iron brackets bolted to a bed plate *J*. Provision for expansion of the shafts due to heat is made by boring the rollers to give a loose fit. The bed plate *J* is bolted to concrete piers and channels *K* bridging between them.

In order to protect the rollers from the heat of the gases and the melted slag at the bottom of the furnace, an octagonal screen of insulating blocks *I* is fastened to the supporting piers and channels. The rollers are also cooled by an air blast from a 12-in. Sirocco fan through four branch pipes on a main air pipe surrounding the furnace. Further cooling of the furnace jacket, belt band, and tire rim is effected by a spray of water from a hose nozzle on the furnace jacket. This also protects the belt from excessive heating.

Slag from the bottom of the furnace is quenched in a drip pan placed between the supporting piers. A constant water level is maintained in the pan by a stream from valve *Z*. The regulation of water level is necessary because of the cooling effect on the bottom opening of the furnace. Excessive cooling causes the slag to congeal and choke the slag exit.

The height of the furnace chamber is increased to 11½ in. by a course of circle bricks *V* to permit placing the burner in such a position that the flame and slag will impinge at the desired height on the test bricks. A crown block *W* is provided with a 5-in. hole in the center which flares out to 12 in. on the underside to permit proper direction of the flame. The crown block is carefully centered in setting up the furnace for a test to insure that the flame and slag impinge uniformly on all the bricks.

5. Feeding of Slag.—It is required that the burner shall deliver an adequate and properly proportioned mixture of gas and air, and at the same time serve as a nozzle to direct a continuous stream of powdered slag against the faces of the brick. The burner shown in Fig. 2 is made up of standard pipe fittings. High pressure air is supplied through a ⅜-in. nozzle inside the upper 1½-in. Y and, by its inspirating effect, draws in additional air through the slag feed opening above. City gas, at a pressure of 10 lb. per sq. in., is supplied through a ½-in. pipe which projects through the lower 1½-in. Y into the mixing nozzle of the burner. The powdered slag, fed into the upper pipe, is carried

in suspension by the air and gas mixture and is projected with the flame on the faces of the test bricks.

The slag, ground to pass a 40-mesh screen, is fed to the burner by a small screw feeder from which it discharges through a slot at one end. The screw, a $\frac{3}{4}$ -in. shaft with a round-bottom thread of $\frac{1}{8}$ -in. pitch, is driven at a fixed speed, ranging from 20 to 40 r.p.m., by a roller chain from a worm-gear speed reducer which is belted to a $\frac{1}{8}$ -h.p. motor. The speed of the screw is regulated to give a desired rate of slag feed.

6. *Driving Mechanism.*—The furnace is rotated at 13 r.p.m. by a 4-in., 5-ply rubber belt passing around the belt band *B* which is cooled by a spray of water on the furnace jacket. Guide rollers and a belt tightener maintain the direction and tension of the belt. Power is furnished by a 5-h.p. motor through a train of spur and bevel gears to the driving pulley which rotates at 25 r.p.m.

III. METHOD OF CONDUCTING TESTS WITH FURNACE

7. *Method of Setting up Furnace for Test.*—The furnace band *E* is first put in place on the bottom blocks which are luted with fireclay mortar. The Sil-o-cel backing bricks are placed inside the band and the test bricks, marked on the outside for identification, are fitted to the circle with the arch bricks *U*, using as thin a fireclay mortar joint as possible. Cracks and spaces between the lining and the Sil-o-cel bricks may be filled with loose grog. The circle bricks are placed on top of the test bricks and the crown block is carefully centered. A luting of fireclay may be placed around the top. The burner should be arranged to permit its being swung aside or removed readily after a test and to allow it to be easily placed in proper position for directing the blast. The belt, which is removed at the end of the test, is put in place and the furnace is started.

8. *Method of Furnace Operation.*—A typical heating curve is shown in Fig. 3. Temperature readings are taken at short intervals by sighting an optical pyrometer on the test brick through the top opening of the furnace. Slag feeding is begun when the furnace temperature reaches 1600 deg. C. and this temperature is maintained throughout the test period, which is usually 24 hours.

The temperature gradient through the test bricks may be determined by use of thermocouples inserted at different depths in the furnace lining, and passing out through the joint in the jacket. It is necessary to stop the rotation of the furnace for a few minutes while

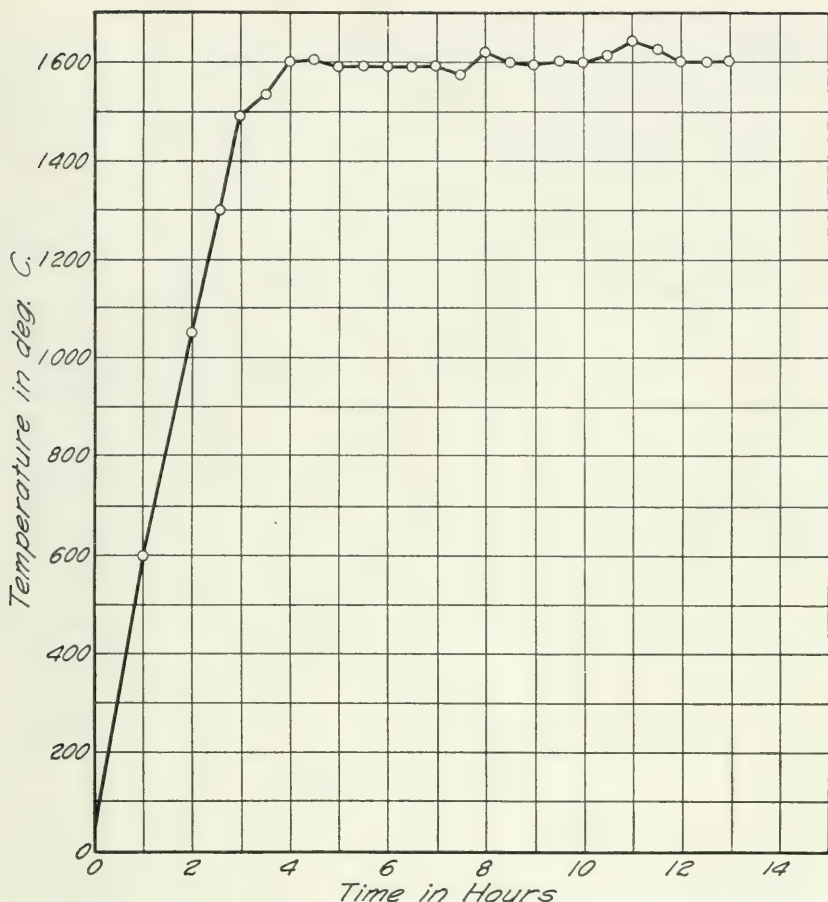


FIG. 3. TYPICAL HEATING CURVE

readings are being taken. The curves in Fig. 4 show temperature readings so taken during one test. The gradient may be varied by the character of the insulation backing the test bricks so as to approximate closely the conditions of service in boiler furnaces or other applications.

Gas samples are taken when desired by means of a water-cooled sampling tube inserted through the top opening of the furnace. A slightly reducing condition, with from 2 to 4 per cent CO, has been used in the tests to simulate the conditions found in boiler furnaces. Little regulation of the burner is required after the final temperature is reached and atmospheric conditions are therefore quite constant. A

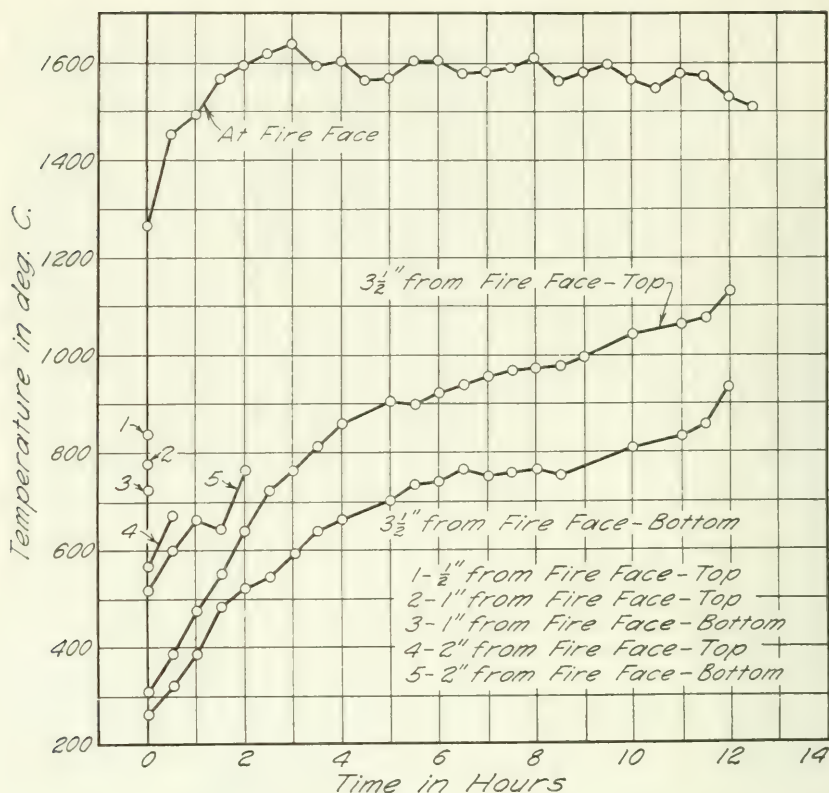


FIG. 4. TEMPERATURES IN TEST BRICK

considerable range in furnace atmosphere is possible with proper burner regulation and, possibly, with the use of preheated air and gas.

In a number of tests synthetic slag was used. This was prepared by sintering together the raw materials and grinding to 40-60 mesh. The composition was based upon that of an Illinois coal ash with a reduction in the contents of Al_2O_3 and SiO_2 to increase the activity of the slag at temperatures used in testing, and thus obtain a large amount of erosion of the bricks in a period of from 4 to 16 hours. Coal ash, taken from the ash pits of boiler furnaces or prepared by burning coal under regulated conditions and then grinding the slag to the desired fineness, was used in later tests, and gave very satisfactory results in test periods of from 20 to 30 hours. The use of coal ash is preferable because it gives a closer similarity to actual boiler-furnace conditions and the results seem to be quite consistent in a series of tests.

9. *Removing and Measuring Test Bricks.*—When the furnace has cooled, the top and circle bricks are removed, the band and insulating bricks are taken away and the test bricks are carefully separated by driving a chisel between them. A little chipping and grinding will remove adhering mortar and slag from the sides and edges.

The residual volume of the test bricks is obtained by means of the mercury balance* described by Westman, or, if the bricks are broken, by water or kerosene displacement. Depressions or irregularities along the edges, due to chipping out while cleaning, are filled with plastic clay. The difference between the residual volume and the original volume, determined by the mercury balance before testing, is taken as the volume lost by slag erosion.

Since firebricks vary somewhat in size, and since the area of face exposed to the action of the slag is not the same for all bricks tested, comparison is made on the basis of erosion in cubic centimeters per square centimeter of surface exposed. The face areas of the bricks are determined by linear measurement before testing. Some slight error in the results is introduced by reason of the decrease in residual volume of the brick due to shrinkage of the material back of the slag contact. The volume shrinkage is relatively small in comparison with the amount actually lost by erosion and the error does not seem large enough to seriously affect the comparative results.

IV. RESULTS OF TESTS

10. *Results with Synthetic Slag.*—The condition of test bricks in the furnace at the end of a test is shown in Fig. 5, the top and circle bricks being removed. Typical results of a test in which synthetic slag was used are shown in Fig. 6—Test A. Five brands of commercial bricks in groups of three each are shown with whole bricks of the same brands placed alongside for comparison. The volume losses for the individual bricks are shown in Table 1.

A comparison of the best and the poorest bricks in this test is shown in Fig. 7. The appearance of the bricks in the furnace after the test, Fig. 5, shows the three samples of brand A standing out noticeably beyond the other test bricks. In all cases the individual bricks of each brand are separated to insure an equal slag treatment in all parts of the lining of the furnace.

The results of a test of five brands of commercial bricks, which were reported to be among the best in service in boiler furnaces using

*Westman, A. E. R., Jour. Amer. Cer. Soc., 9, 5-311, 1926.



FIG. 5. INTERIOR OF FURNACE AFTER TEST

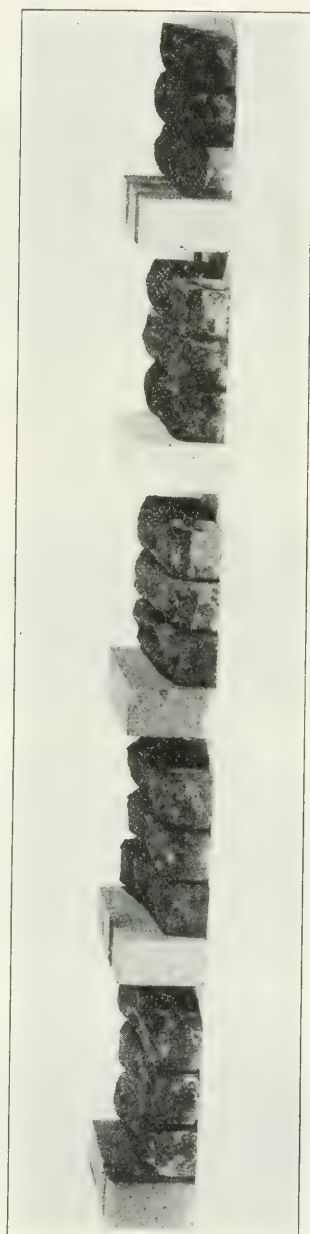
certain grades of Illinois coal, are shown in Fig. 6—Test B. The measured volume losses of the individual bricks are shown in Table 2.

The uniformity of results on the bricks of each brand and the relatively small difference in the losses of the five brands indicate a good comparison of the test results with the results in service. A longer test period and a larger amount of slag was used in this test than in the first one and the volume losses, therefore, are not directly comparable. Comparison of resistance should be based on the results with some standard brand or brands of brick used in each test.

11. *Results with Coal-Ash Slag.*—The results of three tests in which the slag used was coal ash taken from the ash pit of a boiler furnace are shown in Fig. 8. The temperature was maintained at 1600 deg. C. (2900 deg. F.) throughout the slagging period in each test. The slagging periods were 14, 30, and 33 hours, respectively. The volume loss of the bricks in these tests was much less than in the previous tests with synthetic slag, but the comparative rating of the bricks was much the same. The action of the coal-ash slag on individual bricks of a given brand is quite consistent. Microscopic examination of the



Test A



Test B

FIG. 6. RESULTS OF TESTS WITH SYNTHETIC SLAG



FIG. 7. BEST AND POOREST BRICKS FROM TEST A

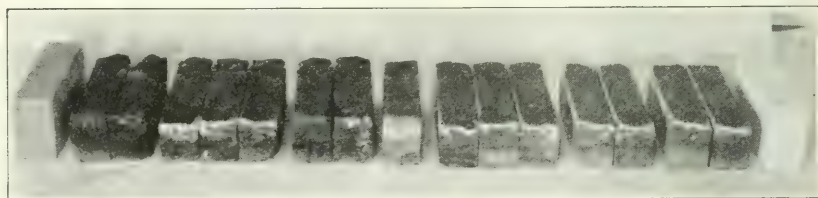
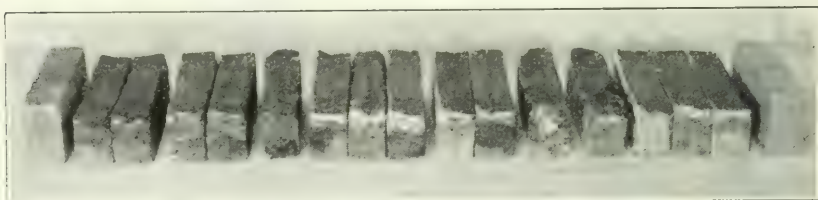
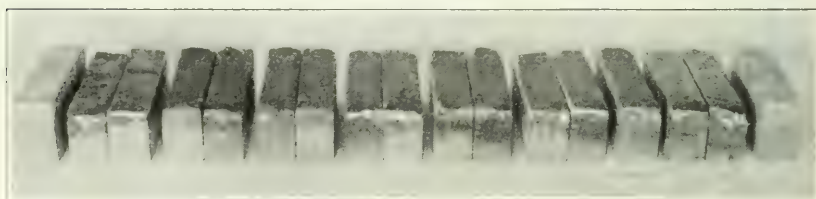


FIG. 8. RESULTS OF THREE TESTS WITH COAL-ASH SLABS

TABLE 1
VOLUME LOSS IN CUBIC CENTIMETERS PER SQUARE CENTIMETER EXPOSED AREA

Brick Number	Brand of Firebrick				
	A	B	C	D	E
1	3.63	4.65	4.74	5.12	5.12
2	3.67	4.80	4.87	5.26	5.33
3	3.72	5.12	4.95	5.37	5.33
Av.	3.67	4.86	4.85	5.25	5.26
Rating	very good	fair	fair	poor	poor

TABLE 2
VOLUME LOSS IN CUBIC CENTIMETERS PER SQUARE CENTIMETER EXPOSED AREA

Brick Number	Brand of Firebrick				
	A ₂	B ₂	C ₂	D ₂	E ₂
1	4.16	4.16	4.25	4.62	5.00
2	4.19	4.23	4.36	4.63	5.08
3	4.29	4.26	4.48	4.65	5.32
Av.	4.21	4.22	4.36	4.63	5.13

slag contacts in these bricks shows action closely resembling that occurring in the boiler furnace under service conditions.

V. SUMMARY

12. *Advantages of This Type of Furnace.*—The advantages of this type of furnace and testing method might be summarized as follows:

(1) All the bricks in a test are subjected to identical conditions of temperature and heat treatment and to equal amounts of slag supplied at a uniform rate.

(2) The temperature gradient through the brick may be controlled by the arrangement of insulation to conform closely to service conditions.

(3) The application of the slag is such that flow over the surface of the brick is a large factor in the erosion, as it is in service.

(4) Atmospheric conditions in the furnace are under close control and may be made to correspond with those in service.

(5) The use of full-sized test brick gives results as nearly quantitative as can be reasonably expected. The arrangement of

the brick takes into account the "skin effect" which sometimes is a factor in the resistance to slag action.

(6) A sufficient number of samples can be tested at one time to give reliable results, and comparison can be made with one or more brands used as standards.

(7) The test is easily arranged and conducted and may be completed with satisfactory results in a period of 24 hours with coal-ash slags.

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